

**Testimony of Daniel F. Lester
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**before the U.S. House of Representatives
Committee on Science, Subcommittee on Space and Aeronautics**

**in the hearing
“Lunar Science & Resources: Future Options”**

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Mr. Chairman and Members of the committee, thank you for this opportunity to appear and give testimony concerning future options for using the Moon to do science. As a member of the space astronomy community, I have been asked to express current thinking about the advantages and disadvantages of the Moon for doing astronomy and, in particular, whether the Moon is an appropriate site for astronomical telescopes. The importance of space telescopes both to fundamental science and to the excitement that the public has about our national efforts in space, combined with the key role that the Moon plays in the President’s new space initiative, give special importance to this issue. In summary, and upon careful recent review of lunar observatory concepts that have been presented over the years, my colleagues and I find that the opportunities for lunar-based astronomy offer much less value, compared to observatories in free space, than had been anticipated several decades ago. While the lunar surface is not a highly enabling site for an astronomical observatory, development of the Moon would need many technologies that would substantially advance telescopes in free space.

Space Astronomy as a National Priority

I want to begin this testimony by reviewing the reasons that we do astronomy — answering some of the most far-reaching and exciting scientific questions that challenge our nation. While studies of our own solar system are increasingly dominated by actual visits by robotic craft, and soon humans, studies of the universe beyond depend entirely on telescopes that detect energy coming from it. While our solar system provides us with clues about the formation of our Earth and the way that life formed upon it, the universe beyond offers insights into extremes of the physical world that are impossible to replicate in our laboratories. We seek to understand the structure and evolution of the cosmos on both the largest scales, reaching back to its earliest times, and on the smallest scales, in the vicinity of black holes. We want to learn how galaxies, stars, and planetary systems form and evolve, their cycles of matter and energy, and understand the diversity of worlds beyond our own. We want to search those worlds for those that might harbor life. Such explorations provide us with not just intellectual satisfaction and national pride in scientific accomplishment, but with new understanding that is the foundation for future technologies. By looking at our universe far away, we better understand the physical world nearby.

Space as an Enabling Site for Astronomical Telescopes

But why do we go into space to do it? Large telescopes are ubiquitous on terrestrial mountaintops, and with roads, power lines, and air to breathe such telescopes are much easier to build and operate than those in space. For several different reasons, it is the vacuum of space that is extraordinarily enabling for astronomy. The atmosphere of the Earth, while essential for life here, distorts and blocks much of the light that comes from the cosmos. That our atmosphere effectively blocks gamma rays, x-rays, and ultraviolet light is critical to our survival, but makes direct studies of black holes and supernovae difficult. That our atmosphere contains water vapor that blocks most infrared light makes studies of star and planet formation especially challenging, though such water is crucial to our existence. In the vacuum of space there is no such impediment. The sky from space is profoundly clear, and this clarity has been utilized by the Compton and Chandra observatories to explore the universe at high energies, the recent Spitzer observatory in the infrared, as well as the Hubble telescope for visible light. For infrared telescopes in particular, in which cryogenic operation offers a dramatic increase in sensitivity, such operation is impossible in the presence of an atmosphere, which would freeze out on a cold telescope. So the vacuum of space offers important thermal advantages.

Astronomical Observatories and the Lunar Surface

Some forty years ago, the Moon was first proposed by astronomers as a prime site for large telescopes. The lack of an atmosphere offered an unobscured view of the cosmos, and the lunar surface offered a “platform” on which to anchor big structures. At this time, the concept for observatory operation was strongly human-intensive, modeled on the operations plan for ground-based telescopes of the era. Humans would be needed, it was thought, not just to handle the (now obsolete) photographic plates that were the sensor-of-choice in that era, but to look through an eyepiece to point and guide the telescope! With a facility firmly anchored to the lunar surface, astronauts could inhabit the observatory and go about their jobs without jiggling the telescope. One or two decades later, with astronauts actually walking and doing science on the Moon, this idea of lunar telescopes gained credibility in the science community. Then, and to this day, astronomical telescopes on the Moon were understood to offer vastly greater capabilities than they would on the surface of the Earth. If the surface of the Moon and the surface of the Earth were the only places able to host large astronomical telescopes, and if cost were not an object, the Moon would win handily in science potential.

Within the last two decades, however, there has been a revolution in our capabilities to autonomously deploy, stabilize, and point satellites in the vacuum of free space. This understanding was gained from both military and commercial (Earth resources) surveillance investments, as well as from the communication satellite industry. Telescopes in free space now track with a precision that is far higher than can telescopes on the ground. Even for arrays of widely separated telescopes that are optically coupled, and offer big advantages in image clarity, implementation strategies have been designed for free space that offer low risk. Finally, information is now returned electronically, rather than on material media, such as photographic plates. While human involvement

has been in at least most contemporary cases unnecessary for startup, the Hubble telescope proved that astronaut roles in mission assurance and servicing could be highly enabling for astronomy. Our space program, as well as that of other countries, has achieved huge successes in astronomy from telescopes in free space.

Dirt and Gravity are No Friends to Telescopes

In comparison to zero-g sites in free space the Moon, as a telescope platform, offers mainly dirt and gravity. While dirt has been viewed by some as providing harvestable resources, it also translates into serious performance liabilities. Surface dust kicked up by both meteorites and activity near the telescope (whether blast waves from rockets or footsteps of astronauts) will degrade optical surfaces. This will result in a reduction of sensitivity and a sharp increase in background light that suppresses the faintest infrared light from distant stars and extrasolar planets. It also dramatically enhances scattered light that will interfere with studies of solar systems in the vicinity of bright stars. This dust, the deleterious properties of which are well understood from Apollo efforts, can be assumed to increase wear and reduce performance of loaded mechanical bearings, on which such lunar telescopes would critically depend for precision motions.

Compared to the weightless environment of free space, even the 1/6g of the Moon will threaten the precise optical alignment of telescopes as they move across the sky. In order to achieve the stiffness needed to avoid such gravity deformations, a lunar telescope will have to be much more massive, and concomitantly more expensive, than a similar telescope in free space. Consider, for example, that the 6 meter diameter James Webb Space Telescope (JWST), now being designed for free space, will have a mass of about six metric tons. Similar sized telescopes on Earth each have about three hundred metric tons of material that has to move, almost an order of magnitude larger than JWST when scaled to the lowered lunar gravity. Finally, gravity is something that lunar surface telescope builders would need to fight. All parts and subsystems brought from the Earth must survive soft landing on the Moon, a requirement that involves considerable added expense and risk. In short, we should ask whether dirt and gravity offer any general value to astronomy. The answer, I believe, is no.

Concepts for lunar telescopes have been proposed that take advantage of special properties of the Moon. The orbit of the Moon is such that telescopes within craters at the lunar pole would never have sunlight shining on them. These telescopes would naturally be extremely cold, perhaps 40-50K, and in this respect could offer excellent infrared performance without expendable cryogenics or costly refrigeration. While noteworthy, this property of the Moon is no longer particularly enabling, as such temperatures are achievable in free space, using lightweight reflective shields to block the sunlight. The Spitzer Space Telescope is at least partly passively cooled using such sun shields, and the thermal performance actually realized for that observatory is identical to engineering predictions. JWST will use shields with more layers, and these models predict achievable telescope temperatures of 35K. We can do even better. The Single Aperture Far Infrared telescope (SAFIR) is a cold telescope facility even larger than JWST, roadmapped as a Vision Mission candidate for the next decade. I am the Principal Investigator on a

concept study for SAFIR. Our team believes that with lessons learned from JWST, and optimized shielding, even lower temperatures can be realized passively. The lunar poles are indeed very cold places but with sunlight properly screened, free space is as well.

The far side of the Moon is also claimed to be scientifically noteworthy as a radio-quiet site. On this hemisphere of the Moon there is never a line-of-sight to the Earth, so the strong human radio traffic and natural radio emission from our planet cannot interfere with astronomical observations there. While this is potentially enabling, the scientific need for such a radio quiet site has never been entirely persuasive. The potential of this site was discussed, but never included explicitly, in the Decadal Study of astronomical priorities by the National Academy of Science. Recent significant developments in strategies for radio frequency noise mitigation may also pertain to this.

It's Not Humans versus Robots

A final advantage that has been ascribed to the Moon for space astronomy is that it is where people will be. I believe I speak for my community in saying that the involvement of astronauts in space astronomy has enormous potential. We look ahead even in the near term to telescopes that do not fit, fully deployed, into launcher shrouds (c.f. JWST). Such telescopes need to be packed, unfolded, locked tight, aligned, and verified, all carrying significant risk if done autonomously. The advantages of in situ astronauts holding screwdrivers and wrenches who are there to deploy and assemble large space telescopes, and rescue these expensive assets in the event of a technical failure (c.f. HST) cannot be dismissed. But if astronauts are going to be based on the Moon, and if we believe they will visit Mars, we will certainly have the capability to put these astronauts to use in free space to advance astronomy, whether in low earth orbit as for HST, or farther out. For example, the semi-stable Earth-Moon and Earth-Sun Lagrange (or libration) points in free space are understood to offer huge advantages to astronomy, and current plans call for a whole squadron of science missions at the latter site within the next two decades. No credible discussion of space astronomy can be had without considering the impressive science potential of these Lagrange points in the Earth-Moon system. As a result, it would be truly unfortunate if astronaut involvement in the future of space science was limited to opportunities with dirt underfoot.

The new space initiative is a bold vision that promises rich payoffs, and gives our nation a defining challenge. National leadership to accrue from this vision and the sustainability with which it is pursued will depend upon careful consideration and strategic pursuit of science opportunities. Such opportunities are founded in curiosity and the spirit of exploration, which are historically established parts of our national heritage and very much key national needs. The Moon offers many such opportunities, but for space astronomy the real value of lunar development will come from how well such development serves observatories elsewhere.